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Abstract.—Concomitant with increasing numbers of the Double-crested Cormorant (*Phalacrocorax auritus*), catfish producers in eastern Mississippi and western Alabama have reported damage caused by cormorant predation. VHF telemetry was used to document movements of 25 cormorants from all known night roosts in the aquaculture producing areas of eastern Mississippi and western Alabama, January-April 1998. A total of 193 day locations and 396 night roost locations of the cormorants were obtained. Each cormorant was found in the study area for 57 ± 4 (SE) days. Each cormorant averaged three night roosts (range: 1-8) and spent 20 (±2) days at each night roost site. Over 95% of cormorant day locations were within 19 km of their night roosts. Catfish pond use by cormorants varied between roost sites. Cormorants from five of eleven night roosts had ≥30% of subsequent daytime locations on catfish ponds and birds from five of the six remaining night roosts did not visit catfish ponds on the following day. Foraging distance and frequency of night roost interchange was less for birds in this study than those reported from other aquaculture regions. We suggest roost harassment efforts should be focused on specific roost sites and some roost sites should serve as unharrassed refugia from which cormorants are less likely to cause damage to aquaculture. *Received 7 October 2002, accepted 17 July 2003.*

Key words.—Catfish, cormorants, *Ictalurus punctatus*, *Phalacrocorax auritus*, radio-telemetry, roost dispersal, roost harassment, predation.

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The interior population of the Double-crested Cormorant (*Phalacrocorax auritus*) breeds mainly in the Great Lakes and prairie pothole regions of North America and winters primarily in the southeastern (southeast) United States (Hatch and Weseloh 1999). This population has increased dramatically over the past two decades (Buckley and Buckley 1984; Hatch 1984, 1995; Krohn *et al.* 1995; Weseloh *et al.* 1995). In the Great Lakes region, approximately 200 nests were found in 1968 and 1973 (Ludwig 1984), 38,000 in 1991 (Weseloh *et al.* 1995), and 93,000 nests in 1997 (Tyson *et al.* 1999). Approximately 115,000 cormorant nests were found in the Great Lakes region during 2000 (D. V. C. Weseloh, unpubl. data).

The increase in the number of cormorants wintering in the southeast has mirrored the increases in the Great Lakes region and has coincided with a dramatic increase in commercial production of Channel Catfish (*Ictalurus punctatus*) in the southeast (Glahn and Stickley 1995; Mott and Brunson 1997; Glahn *et al.* 1999, 2000a). The largest concentration of catfish farming is in the delta region of Mississippi, but eastern Mississippi and western Alabama (Fig. 1) have experienced the most rapid growth in area devoted to catfish aquaculture in the

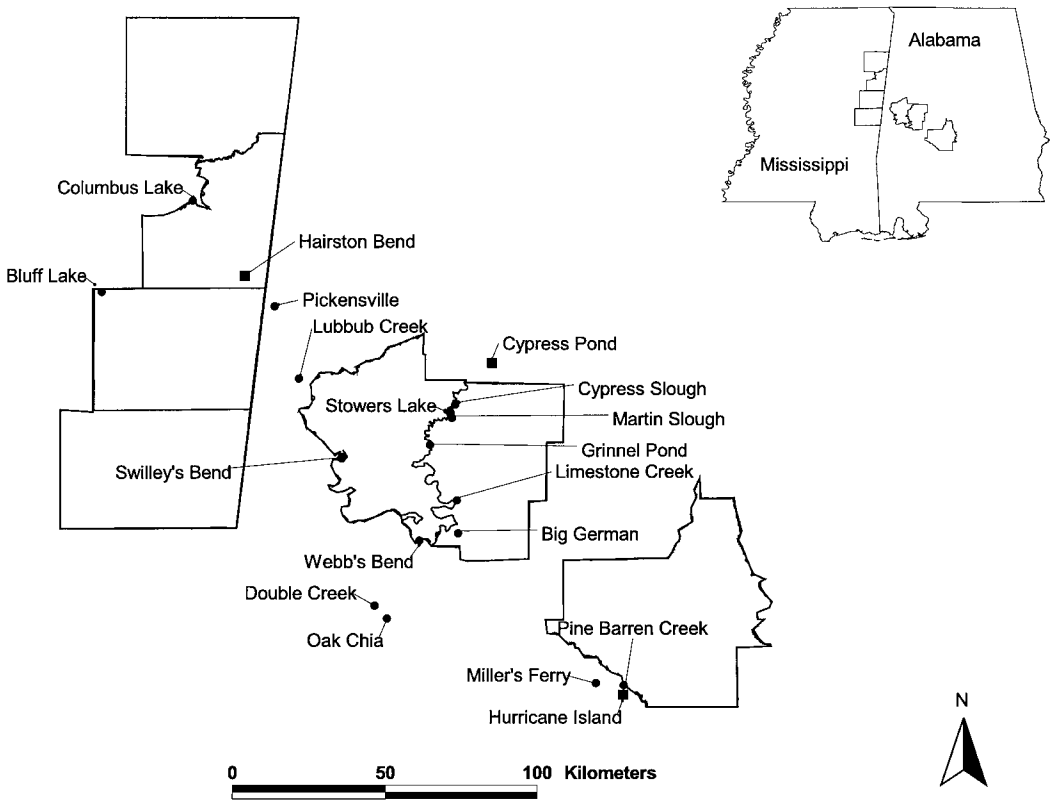

Figure 1. Nineteen night roost locations (closed circles; closed squares represent sites that were also capture locations) used by Double-crested Cormorants in the eastern region of Mississippi and western region of Alabama. County outlines represent the primary aquaculture producing regions of eastern Mississippi and western Alabama.

United States (Ray 1999). Eastern Mississippi and western Alabama currently have about 4,000 and 7,900 ha of water in production respectively, producing approximately 61 million kg (live weight) of farm-raised catfish in 1999 (NASS 2000; Vanderberry 2000).

The increases of both cormorant numbers and catfish production have led to increased conflicts and concern over economic impacts associated with cormorant predation at catfish farms (Glahn *et al.* 2000a). Extensive research has investigated the impact of cormorants on catfish aquaculture in the delta region of Mississippi (Glahn *et al.* 2000b), where catfish production was initiated over 30 years ago (Ray 1999). Large-scale catfish aquaculture was more recently established in eastern Mississippi and western Alabama (Ray 1999) and, as a consequence, less research has been done and less information is available concerning cormorant depredation in these areas. However, approximately 16,500 and 22,000 cormorants were reported from night roost counts in the primary aquaculture areas of eastern Mississippi and western Alabama in the winters of 2000-01 and 2001-02, respectively (J. Feist, unpubl. data).

Efforts to reduce cormorant predation on aquaculture facilities consist mainly of shooting birds to reduce numbers (Belant *et al.* 2000), frightening birds off aquaculture ponds (Mott and Boyd 1995), and dispersing them from nighttime roosts (Mott and Boyd 1995; Reinhold and Sloan 1999). In 1998, the U.S. Fish and Wildlife Service issued a standing predation order (63 FR 10550) that enabled aquaculture producers in 13 states, (including Mississippi and Alabama) to shoot without a Federal permit, any Double-crested

Cormorants that are causing, or are about to cause, damage on their aquaculture facilities.

Currently, the most effective management technique in the delta region of Mississippi, is a U.S. Department of Agriculture (USDA), Wildlife Services cooperative effort with catfish producers in which a coordinated, region-wide night roost harassment effort is carried out each winter (Mott and Boyd 1995; Reinhold and Sloan 1999). Several nights of harassment with pyrotechnics usually caused cormorants to abandon a roost (Hess 1994; King 1996). Mott *et al.* (1998) reported a ≥70% reduction in predation on catfish after cormorants were dispersed from nearby roosts. The objective of this roost harassment program is to move cormorants away from where catfish farms are concentrated, to areas where there is a lower fish farm density and more natural habitat, such as along the Mississippi River and adjacent oxbow lakes (Glahn and Stickley 1995; Glahn *et al.* 1998; Glahn *et al.* 2000b; Tobin *et al.* 2002).

No cooperative and coordinated roost harassment program existed in eastern Mississippi and western Alabama at the time of this study. Harassment of night roosts in these areas was sporadic and typically occurred only when a producer filed a complaint concerning cormorant predation (USDA, Wildlife Services, unpubl. data). Uncoordinated roost harassment has been shown to be ineffective in moving birds away from aquaculture producing areas because birds typically relocate to the nearest nonharrassed roost site (King 1996; Mott *et al.* 1998; Tobin *et al.* 2002).

Radio telemetry studies provided insight on movement patterns of cormorants in relation to aquaculture. King *et al.* (1995), King (1996) and Tobin *et al.* (2002) used VHF radio telemetry to determine activity budgets, foraging behavior, and gender differences related to foraging on aquaculture, and to evaluate the effectiveness of roost harassment programs.

The objectives of this study were to evaluate cormorant movements from known roost site locations with respect to primary aquaculture producing areas of eastern Mississippi and western Alabama and to develop management recommendations concerning cormorant depredation for these areas. We were specifically interested in (1) identifying roost sites from which cormorants foraged primarily in aquaculture producing areas (2) identifying roost sites from which cormorants foraged primarily outside of aquaculture producing areas (3) determining roost fidelity of cormorants, and (4) evaluating differences in movements of male and female cormorants.

METHODS

The study was conducted in east-central Mississippi and west-central Alabama, an area of approximately a 14,000 km^2 in the East Gulf Coastal Plain physiographic region (Mettee *et al.* 1996). The primary watersheds include portions of the Upper and Lower Tombigbee, Black Warrior, and Alabama Rivers (Mettee *et al.* 1996). Most of these watershed areas are used for timber production or have been drained and cleared for intensive cultivation of cotton, soybean, livestock, and catfish. The river systems have been extensively modified through locks and dams and contain over 100,000 ha of impoundments (Mettee *et al.* 1996). We used methods described by King *et al.* (1994) to capture 26 cormorants at three roost sites (3 at Cypress Pond, 3 at Hairston Bend, and 20 at Hurricane Island) during 6 January-24 February 1998 (Fig. 1). We attached a 25 g (1-2% of body weight), backpack-mounted radio-transmitter (166.006-166.990 MHz, Advanced Telemetry Systems, Inc.®, Isanti, MN) to each bird (Dunstan 1972) and released it within two hours of capture. Morphometric measurements were used to determine the sex of each bird (Glahn and McCoy 1995). The cormorants were tracked from 27 January to 15 April 1998.

To determine cormorant daytime locations, we flew once a week over the aquaculture areas of eastern Mississippi and western Alabama, encompassing all known night roost sites for this region (Fig. 1). Flights began at about 08.00 h, proceeded in a grid pattern over the study area at an altitude of approximately 500 m, and were concluded by 16.00 h. We flew in a Cessna 172 fitted with FAA-certified dual three-element yagi antennae mounted on the wing struts and Advanced Telemetry Systems, Inc.® (ATS, Inc.®) R4000 VHF receivers to detect signals. During aerial observations, the bird location (latitude and longitude), date, time, transmitter frequency, and sitetype (catfish pond, lake, river, day roost) of all detected signals were recorded. Latitudinal and longitudinal coordinates of birds were determined by either a ground-based long-range navigational system (LORAN) or global positioning system (GPS).

To determine night locations, three observers monitored 19 night roosts twice weekly from the ground. Night roost locations were checked <24 h prior and <24 h subsequent to recording daytime aerial locations, allowing identification of night roosts in relation to feeding sites. All observers used three-element yagi antennae and R4000 receivers (ATS, Inc.®). An observer monitored the presence of cormorants at 15 of 19

known night roost locations along a transect between sunset and sunrise two nights/week (Tobin *et al.* 2002). The transect extended about 163 km from Bluff Lake, Mississippi, down the Tombigbee River to Oak Chia, Alabama, then up the Black Warrior River to Cypress Pond, Alabama (Fig. 1). Three additional night roosts were monitored on the Alabama River near Camden, Alabama (Fig. 1) and one site was monitored on Columbus Lake, Mississippi (Fig. 1). During night roost observations, the roost location (latitude and longitude), date, time, and transmitter frequency of all detected signals were recorded.

King *et al.* (1995) have shown that a cormorant forages for about 1 h per day and loaf or day roost for much of the remainder. Therefore, we evaluated daytime locations based on whether the birds were on catfish ponds or not, and whether the locations were inside or outside primary aquaculture producing areas of eastern Mississippi and western Alabama. The primary aquaculture areas for eastern Mississippi were taken as the counties of Noxubee, Lowndes, Kemper, and Monroe, and for western Alabama as the counties of Dallas, Greene, and Hale (Fig. 1). These counties account for 84% and 76% of the total water area in catfish production within eastern Mississippi and Alabama, respectively (NASS 2000; Vanderberry 2000).

Because Glahn *et al.* (1996) and Tobin *et al.* (2002) reported gender differences in distances moved and utilization of aquaculture in the delta region of Mississippi, these factors were evaluated with respect to movements of males and females in the aquaculture area of eastern Mississippi and western Alabama. Analysis of variance and Tukey's Studentized Range Test (SAS Institute 1994) were used to determine differences in distances traveled from night roosts to subsequent day locations and subsequent night roost locations for males and females. Chi-square tests were used to compare classification data (SAS Institute 1994). Yates' continuity correction was used whenever cell frequencies were less than five (SAS Institute 1994).

RESULTS

Signals from 25 of the 26 birds fitted with radio-transmitters were located during the 15 weeks that we monitored their movements (Table 1). Each of these 25 birds was tracked for a mean (±SE) of 57 ± 4 days (range: 14-81). We detected 193 post-capture day (aerial) locations and 396 post-capture night roost locations. Overall, locations for 36-95% of the birds were determined each week (Table 1). During the weeks in which both aerial and ground locations were obtained, an average of over 75% of the cormorants available for tracking were located. During weeks 5-10 an average of 92 % of the marked cormorants were located. There was not a decline in the number of birds located until late March (week 13).

The average of 24 ± 2 (N = 25, Range: 5-40) days with both day and night locations was per bird. The average number of days each of the 25 cormorants was found in the study area was 57 ± 4 (N = 25). Eighty-five (44%) of the total number of day locations were within primary aquaculture areas. Forty-seven (55%) of these locations were on catfish ponds, whereas only 10 (9%) of locations outside the primary aquaculture areas were at catfish ponds. Of the 25 cormorants for which we had day locations, 15 were male and ten were female. We found no difference in the total number of locations for males and females foraging on catfish ponds versus "other" areas ($\chi^2_1 = 1.81$, n.s., N = 193) or the number of individuals of either sex foraging on catfish ponds or "other" areas ($\chi^2_1 = 0.30$, n.s., N = 42).

During night monitoring, a mean of 16 ± 2 locations was determined for each of 25 cormorants. These 25 birds roosted in 15 different locations, averaging three roosts per bird. Each of the 25 birds averaged 20 (±2) days at each roost site. For eleven of the 15 night roost locations, 101 subsequent (<24 h) day

Table 1. Numbers of Double-crested Cormorants fitted with radio-transmitters and located weekly from 27 January-15 April 1998 in eastern Mississippi and western Alabama, USA.

	Study week															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Overall
No. captured	1	0	14	5	3	0	0	3	0	0	0	0	0	0	0	26
No. in study	1	1	14	19	22	22	22	25	25	25	25	25	25	25	25	25
No. located	—	—	—	12	21	21	19	23	17	23	17	19	15	13	9	25
No. located at night roosts	a	a	a	12	19	19	19	22	17	21	17	15	10	6	6	25
No. located during the day	b	b	b	b	20	15	15	22	b	21	b	17	15	13	7	25

[a]No ground tracking conducted.
[b]No aerial tracking conducted.

(aerial) locations were obtained. Sixty-five of these locations were for cormorants that roosted at Hurricane Island. However, less than 5% of the day locations of birds roosting on Hurricane Island were found on catfish ponds (Table 2). Five night roosts had over 30% of subsequent (<24h) cormorant day locations on catfish ponds (Table 2). Cormorants at four of the remaining five night roosts had no locations on catfish ponds (Table 2).

Differences among roost sites were more pronounced for subsequent (<24 h) day locations inside or outside the major aquaculture areas. Cormorants from five of the eleven night roost sites for which we recorded subsequent day locations had all of their subsequent daytime locations within the major aquaculture producing areas. Cormorants from the remaining six night roost sites had no subsequent day locations within the major aquaculture producing areas (Table 2). Again, Hurricane Island accounted for the majority (64%) of subsequent (<24 h) day locations, with all of the locations being outside of the primary aquaculture producing areas (Table 2). Day locations for nine birds were exclusively outside of the primary aquaculture areas, four birds were exclusively in primary aquaculture areas, and twelve used both areas.

Distance data from night roosts, subsequent (<24 h) day foraging locations, and subsequent (<24 h) night roost locations were available for 24 of the 25 cormorants. Of these 24 birds, 15 were male and nine were female. No gender differences in the distance moved from night roosts to day foraging locations were found ($F_{1, 22} = 1.15$, n.s.). The mean (±SE) distance moved for males and females combined was 7.9 ± 1.1 km (N = 24). The maximum distance moved over the study period was 113 km.

DISCUSSION

Cormorant Movements

We found many contrasts in the movements of cormorants in the aquaculture areas of eastern Mississippi and western Alabama compared with those in the delta region of Mississippi. King (1996) found some cormorants moved as much as 350 km to the Mississippi and Alabama Gulf Coast. In weeks in which both ground and aerial tracking were conducted, Tobin *et al.* (2002) located on average 18% fewer marked cormorants each week and presumed that many of the birds not located had left the study area. Tobin *et al.* (2002) also recorded distances moved from night roost to day locations that were approximately three fold greater than the average distances moved (7.9 km) for cormorant's in the current study. Cormorants in our study foraged in relatively close proximity to their night roosts. Unlike Glahn *et al.* (1995) and Tobin *et al.* (2002), we found no gender differences with respect to daily distances moved or the frequency of foraging on catfish ponds and occurrence in primary aquaculture areas. Our data suggest that male and female cormorants in eastern Mississippi and western Alabama remained in the study area for most of the study period.

Table 2. Number (and percentages in parentheses) of Double-crested Cormorant locations on catfish ponds (CFP) or other sites (day roosts or natural water bodies) and the number of these locations found inside (In) or outside (Out) of the primary aquaculture regions of eastern Mississippi and western Alabama, USA, in relation to the (<24 h) night roost location from 27 January to 15 April, 1998.

	Roost name										
Location	Cypress Pond	Cypress Slough	Hairston Bend	Hurri-cane Island	Lubbub Creek	Martin Slough	Miller's Ferry	Pickens-ville	Pine Barren Creek	Swilley's Bend	Webb's Bend
CFP	1 (100)	0 (0)	1 (13)	3 (5)	2 (40)	0 (0)	0 (0)	1 (33)	0 (0)	3 (75)	3 (60)
Other	0 (0)	3 (100)	7 (87)	62 (95)	3 (60)	3 (100)	1 (100)	2 (66)	3 (100)	1 (25)	2 (40)
In	0 (0)	3 (100)	8 (100)	0 (0)	0 (0)	3 (100)	0 (0)	0 (0)	0 (0)	4 (100)	5 (100)
Out	1 (100)	0 (0)	0 (0)	65 (100)	5 (100)	0 (0)	1 (100)	3 (100)	3 (100)	0 (0)	0 (0)

Cormorants in this study used an average of three roosts for about 20 nights per roost during the study period. While the average number of night roosts used by each cormorant was similar to that reported by Tobin *et al.* (2002), the average number of days we tracked cormorants was nearly twice as long. This suggests that cormorants in eastern Mississippi and western Alabama changed night roosts less frequently than cormorants in the delta region of Mississippi.

Sixteen (64%) of all marked cormorants had day locations within the primary aquaculture producing areas. In addition, 55% of all day locations within the primary aquaculture producing areas were on catfish ponds. However, utilization of the major aquaculture producing areas and frequency of foraging on catfish ponds varied greatly in relation to the previous night's roost location. Hurricane Island was the most frequently used night roost location yet accounted for few of the subsequent cormorant foraging locations on catfish ponds or in the aquaculture producing areas. Although sample sizes for other roosts were small, it appears that roosts along the Black Warrior River and Lower Tombigbee River provided the greatest percentage of subsequent cormorant locations on catfish ponds and inside primary aquaculture producing areas. The exceptions to this were Pickensville and Lubbub Creek, both of which were outside of the primary aquaculture areas yet still had relatively large percentages of locations on catfish ponds.

No locations of marked birds were obtained from four of the 19 known roost locations. Two of these (Double Creek and Oak Chia) were outside of the primary aquaculture producing areas, and one (Bluff Lake) was distant from the three primary river drainages (Tombigbee, Black Warrior and Alabama Rivers). The remaining location (Grinnel Pond), although historically used (Wildlife Services, Alabama, unpubl. data) and within the primary aquaculture producing areas, was not used by marked cormorants in this study. Glahn *et al.* (1996) reported annual shifts in use of night roosts in the delta region of Mississippi and noted that roosts that historically were used by large numbers of cormorants may be visited by few birds, or not at all in some years. Future monitoring of roost sights should provide insight into inter-year roost fidelity in eastern Mississippi and western Alabama.

Management Implications

Cormorants cause economic losses to the catfish aquaculture industry (Glahn and Stickley 1995; Glahn and Dorr 2002; Glahn *et al.*, in press). Development of strategies for managing cormorant predation would be beneficial to catfish producers as well as the agencies mandated with implementing solutions to depredation problems.

A cormorant roost dispersal program can be an effective component of an integrated approach to reducing cormorant impacts to aquaculture (Mott *et al.* 1998). However, for this type of management strategy to be successful, cormorants must be able to be dispersed to an area that provides a refuge from which they will forage less on aquaculture and more in natural habitats (Glahn *et al.* 1995; Mott *et al.* 1998; Tobin *et al.* 2002).

Ninety-five percent of all cormorant day locations were within 19 km (mean ± 2 SD) of their night roosts. Cormorants changed night roosts approximately every 20 days, and for some roosts rarely foraged on catfish ponds or visited primary aquaculture producing areas of eastern Mississippi and western Alabama. These data suggest roost harassment should be focused on specific roost sites and other sites should be left undisturbed to serve as refugia from which dispersed cormorants are less likely to cause damage. We suggest that the birds using the night roosts at Hurricane Island, Miller's Ferry, and Pine Barren Creek should not be dispersed because cormorants from these roosts seldom forage on catfish ponds or frequent primary aquaculture producing areas. Double Creek and Oak Chia roost sites are more than 19 km from primary aquaculture producing areas and are near natural water bodies so they could also serve as refugia for dispersed cormorants. Bluff Lake was not used by cormorants in this study. However, because it is part of a national wildlife refuge it is unlikely it would be an acceptable site for dispersal activities. Cormo-

rants at all other sites in this study are likely to forage on catfish ponds and frequent primary aquaculture-producing areas and should be considered for roost dispersal activities.

Providing refugia may serve two purposes: 1) they allow cormorants to move to areas where they are less likely to cause damage, and 2) they avert the proliferation of night roost sites that occurred in the delta region of Mississippi concomitant with implementation of that region's roost dispersal program (Mott *et al.* 1998; Reinhold and Sloan 1999; Glahn *et al.* 2000). However, cormorant roost utilization is a dynamic process, and two additional roost sites have been found since the completion of this study (USDA, Wildlife Services, unpubl. data). Annual monitoring of cormorant numbers and roost sites will provide insight into the patterns of cormorant utilization of these sites and whether the number of roost sites is increasing.

The aquaculture industry in eastern Mississippi and western Alabama has experienced considerable growth over the past decade (Ray 1999; Vanderberry 2000) and it is likely this pattern will continue. As the aquaculture industry expands, the dynamics between cormorants at specific roost sights and aquaculture depredation will likely change. Additionally, any increase of cormorant numbers will influence the number and patterns of roosts used and cormorant predation and damage management on catfish aquaculture. Given these considerations, monitoring and adaptive management efforts will be key to reducing cormorant predation on aquaculture in eastern Mississippi and western Alabama.

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